Runway Assessment via Remote Sensing

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Available at: https://works.bepress.com/james-aanstoos/7/
Runway Assessment via Remote Sensing

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Abstract—Airport pavements are constructed to provide adequate support for the loads and traffic volume imposed by aircrafts. One aspect of pavement evaluation is the pavement condition which is determined by the types and extent of distresses. These include cracking, rutting, weathering, and others that may affect pavement surface roughness and the potential for FOD (Foreign Object Debris). Pavement evaluations are necessary to assess the ability to safely operate aircraft on an airfield. The purpose of this study is to explore the potential use of microwave remote sensing to assess the pavement surface roughness. Radar backscatter responds to surface roughness as well as dielectric constant. The resulting changes in backscatter can convey information about the degree of cracking and surface roughness of the runway. In this study, we develop a relation between the Terrain Ruggedness Index (TRI) of the runway and radar backscatter magnitudes. Radar data from the TerraSAR-X satellite is used, along with airborne LiDAR data (30 cm spacing). Modest linear correlation was found between the vertical co-polarization channel of the radar data and TRI values computed in 5 by 5 pixel windows from the LiDAR elevation data. Over four different test areas on the runway, the coefficients of determination ranged from 0.12 to 0.46.

Keywords—radar; roughness; pavement assessment

I. INTRODUCTION

To ensure that runways are able to provide adequate support for intended aircraft operations it is important to conduct pavement evaluations. Such evaluations aim to assess possible risks from cracking, rutting, or weathering of the runway due to aging or distress.

The primary means of evaluating runway condition is using surveying methods which require experts to manually assess the asphalt, in order to come to a conclusion about its condition. A method of assessing runway conditions using remote sensing can be useful, either as a more frequent substitute for manual inspections, or for use on runways where access by ground inspectors is not feasible.

In this study, the backscatter from a satellite-based synthetic aperture radar (SAR) is compared with a measure of surface roughness computed from high resolution LiDAR profiles of a paved runway surface, to determine whether such remotely sensed data can be used to estimate aspects of the runway condition.

II. BACKGROUND

Suanpaga and Yoshikazu [1] developed a model to assess highway riding quality using the backscatter of a Phased Array type L-band Synthetic Aperture Radar (PALSAR). They found that an increase in the radar backscatter could indicate poor surface condition.

Evans et al. [2] analyzed dielectric constants using Ground Penetrating Radar (GPR). They noted that porosity, density, mineralogy, constituent material makeup, temperature, radio frequency, and pore fluid content all affect the asphalt dielectric constant. They also listed various values for dielectric constants for asphalt materials used in the UK. They observed large variations in dielectric measurements due to different levels of compaction, and recommended in-situ measurements be taken versus relying on published tables of dielectric constants.

Grohmann et al. [3] analyzed topographic surface roughness using six different techniques. They found that an index based on the standard deviation of slope offered good performance at a variety of scales, along with simplicity of calculation.

Harold et al. [4] investigated road condition mapping with hyperspectral remote sensing. They noted that as the asphalt ages the reflectance of the road increases. Jengo et al. [5] analyzed road conditions by measuring spectral shapes and brightness using Classification Regression Tree (CART) algorithms.

Sayers and Karihamas [6] explain the use of road profiles, profile measurement methods, and models where the road profile data is used to estimate ride quality. Kil and Shin [7] developed an automatic system to classify and identify road distresses using three CFAR (constant false alarm rate) detectors.

Noronha et al. [8] used AVIRIS hyperspectral imagery and field-gathered spectra to investigate the spectral signatures associated with different qualities of pavement. They note that it is possible to estimate the age of asphalt using this technique.

Ahmad et al. [9] used GPR for crack detection in asphalt pavements. Bitelli et al. [10] used high precision laser scanners to characterize surface texture of roads. These methods were accurate, but were limited to assessing the roadway surface.
The Terrain Ruggedness Index (TRI) defined by Riley [11] is closely related to the standard deviation of slope parameter, and this index was chosen for comparison to radar backscatter for the present study.

III. DATA AND STUDY AREA

The test site is an inactive airfield (Hagler AAF) at Camp Shelby near Hattiesburg, Mississippi. The airfield is in fair condition. An optical image of the runway is shown in Fig. 1.

The SAR data used in this investigation is from the German TerraSAR-X satellite. TerraSAR-X and its twin satellite TanDEM-X offer the highest spatial resolution SAR data currently available from a spaceborne platform [12]. The vertically co-polarized (VV) channel of X-band radar data acquired in spotlight mode with a spatial resolution of 50 cm on December 14, 2014 was used for the analysis. The SAR image over the test area is shown in Fig. 2, along with the runway boundary and location of four subsets used for testing.

Airborne LiDAR (Light Detection and Ranging) data was acquired to use as “ground truth” for surface roughness. This was collected on July 15th, 2014 at Hagler Airfield Camp Shelby MS by The Atlantic Group LLC. The data was collected using a Leica ALS70 LiDAR sensor at an altitude of 1614m AGL to support the generation of 1 foot contours, meeting horizontal and vertical accuracy requirements of less than 3 ft. and +/- 0.5 ft. (2 sigma) respectively and producing a point density of 30 points/square meter. The LiDAR collection was supported by ground base stations. All control and check points were made with Leica 500 dual frequency GPS receivers on July 7th, 2014. Control network adjustment was performed using Grafnet & Leica Geosystem Office software. A total of fourteen (14) control and check points were established within the project area of interest. A bare earth DEM (digital elevation model) was produced, from which the roughness index was calculated.

The value of the Terrain Ruggedness Index or TRI was computed from the LiDAR DEM using different window sizes for comparison with the radar backscatter data. The best match was found using a 5 by 5 pixel window, corresponding to a roughly 1.5 by 1.5 meter area. Samples of the TRI values thus computed are plotted in Figure 3, along with representative close-up photographs of the runway surface.

IV. METHOD

Four subsets of the runway surface, in a variety of conditions, were chosen for analysis. Values of TRI were computed for each pixel of the radar data from a corresponding window of LiDAR data with different moving window sizes. Window sizes of 3x3, 5x5, and 7x7 LiDAR pixels were tested. The 5x5 window size was found to have the best fit, and those results are reported here.

The TRI is computed from the LiDAR data for various window sizes as follows:

\[
TRI = \left[ \sum (Z_{ij} - Z_{00})^2 \right]^{1/2}
\]

Here \(Z_{ij}\) = elevation of each neighborhood (window) cell from the LiDAR data, and \(Z_{00}\) is the value at the center of the window.
Regression analysis was performed to investigate potential relationships between the LiDAR-based roughness values and the radar backscatter magnitudes. Linear and polynomial regression models were applied and the coefficient of determination (R-squared value) computed for each.

The TRI values were compared in the regression analyses with the value of the radar backscatter for a pixel centered on the same coordinates (note that the size of the radar pixel does not correspond exactly to the size of the LiDAR data window).

V. RESULTS AND DISCUSSION

The results for the linear regression on TRI values computed using a 5x5 window size are shown in Figure 4 and summarized in Table 1. This case showed the best fit compared to the other window sizes tested. The radar backscatter magnitude increases with roughness as expected from basic radar theory [13], and the analysis showed that the backscatter values in the VV polarization correlated somewhat significantly with TRI values, with the highest correlation occurring in region 3 having R-squared value of 0.46.

Since radar backscatter depends primarily on both surface roughness and dielectric constant, this analysis assumes that the dielectric constant is relatively uniform on the runway. This is a reasonable assumption if the runway is of uniform construction using the same asphalt mixture and not subjected to an accumulation of water, since water content is a significant factor in the dielectric constant. The particular test case used in this study was a dry runway to minimize moisture-based variations in the dielectric constant, and given the uniform surface material (asphalt), this property would not be expected to vary significantly over the area of the runway. Therefore, most of the radar backscatter variation is expected to be due to the variation in surface roughness, and thus the significant correlation with a roughness measure such as TRI is reasonable. In addition to any remaining dielectric constant variations, deviation from a perfect fit can be due to several factors including: radar speckle noise, smoothing of LiDAR profiles due to limited spatial resolution, and different scales of roughness affecting radar. We chose not to apply a speckle filter to the radar data, since it would reduce the spatial resolution and also smooth out the roughness signal.

To make use of these results for remote sensing based runway assessment, one must either assume that moisture content is uniform or that surface roughness factors dominate the backscatter detected. Future work will attempt to quantify the relative effects of these two variables on the detected radar backscatter.

ACKNOWLEDGMENT

This work was sponsored by the Engineering Research & Development Center under Cooperative Agreement number W912HZ-15-2-0004. The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of the Engineering Research & Development Center or the U.S. Government.

Fig. 4. Relationship between Terrain Ruggedness Index (TRI) and radar backscattering magnitudes (dB) of VV polarization data. TRI was computed using a 5 x 5 moving window of LiDAR height values. Panels (a) – (d) shows the relation between TRI and backscatter for four regions of interest.

<table>
<thead>
<tr>
<th>Region of Interest</th>
<th>Window Size</th>
<th>Regression Type</th>
<th>Regression Equation ( (y = m \times x) )</th>
<th>Coefficient of Determination ( (r^2 \text{ value}) )</th>
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<tbody>
<tr>
<td>1</td>
<td>5x5</td>
<td>Linear</td>
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<tr>
<td>4</td>
<td>5x5</td>
<td>Linear</td>
<td>( y = 0.0024692 \times x )</td>
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</table>

REFERENCES


